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Human visual evoked response changes to stimuli in a concept identification task were measured at the vertex and the occipital lobe in an attempt to investigate slow D. C. potential shifts as a function of hypothesis-testing behavior. It was found that when S shifted his hypothesis from one stimulus to another in the learning task, there was a corresponding increase in the positive D.C. potential from the previously hypothesized stimulus to the now-hypothesized one.

Hypothesis-testing behavior was determined by a modified blank-trials procedure in which the stimuli of each trial occurred sequentially. The sequential presentation permitted the measurement of evoked potentials to each of four stimulus dimensions. In order to determine the effects of a motor response, each S had several reaction time and no reaction time problems.

A non-parametric Sign Test indicated that there was a correspondence between S's behavioral response and D. C. shift changes ($p < .01$), especially at the vertex under the reaction time response. Further, an analysis of variance indicated that these changes in the slow positive potentials were related to responding to solution stimuli ($p < .05$).

Interpretation of the results was in terms of a selective attention process reflected by both hypothesis-testing behavior and the slow D. C. potential shifts.

ELECTROPHYSIOLOGICAL ASPECTS OF SELECTIVE ATTENTION DURING CONCEPT LEARNING

by

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Introduction

The differential effects of attention and arousal on cortical evoked responses have been studied extensively in both human and animal conditioning research (Grossman, 1967; Morrell, 1961). By using a blank-trials procedure similar to the one described by Levine (1969), it has been possible to examine these effects in the area of human problem solving. The purpose of the present study was to investigate changes in the magnitude of the Visually Evoked Response (VER) during a concept learning task. Specific emphasis has been placed upon the development of slowly changing, direct current potentials during hypothesis-testing behavior.

Visual evoked potentials can be simply defined as time-locked signals generated by visual stimuli. Due to modern averaging techniques, these signals can be separated from the spontaneous background activity of the brain. The primary locus for recording VERs of maximum amplitude is usually over the occipital lobe, close to the inion, with a secondary maximum region over the vertex. The averaged evoked response is made up of several fairly distinct components, each with a different latency and amplitude. Up to 80 to 100 msec following stimulus onset, there is an early primary sensory response which tends to be

variable both within and across individuals. From 100 to about 300 msec., there are several fairly stable, major components. The most consistent of these late major deflections is a large positive potential which usually occurs around 300 msec. and has been related to the subjective response to the stimulus. Following the late components, are the afterpotentials with latencies of 300 msec. and more (Lindsley, 1969).

It is generally maintained that the early components of the evoked potential (EP) reflect specific activity, while the late and afterpotentials reflect nonspecific activity (Lindsley, 1969). Rose and Lindsley (1968) have suggested that this division may provide a way for identifying the components with certain systems of operation within the brain. They were able to separate activities of a specific and a nonspecific nature in a developing kitten between birth and 30 days of age. From birth to 4 days, they reported only a long-latency negative wave in response to a light flash. At the age of 10 to 15 days, there were two distinct responses. One was a short-latency positive-negative complex, found over the visual area, and the other was the original long-latency negative wave, found over the visual and other nonvisual areas. From 10 to 30 days, the two responses gradually coalesced to form the evoked response seen in the mature cat. Using ablation techniques, Rose and Lindsley observed that lesions of the classical

visual pathway at the lateral geniculate body blocked primarily the specific, short-latency positive-negative complex, while lesions of the superior colliculus removed only the long-latency negative wave. They concluded that there are two separate but interacting systems which operate to form the evoked potential (EP). One is a specific and direct projection to the visual cortex, while the other projects more diffusely through the reticular formation.

Attention, Arousal, and the VER

It has been suggested that the brief phasic component of the VER may reflect activation of the Diffuse Thalamic Projection System which serves a specific alerting or attention function. General arousal is subserved by the Ascending Reticular Activating System and is reflected by the tonic component of the EP. Both of these systems are mediated by the reticular formation of the midbrain, which serves primarily an inhibitory function. Habituation of the evoked response has been related to these inhibitory influences, while facilitation has been related to a release of this inhibition (Grossman, 1967).

It has not been made clear whether these inhibitory effects develop in the reticular formation itself, as a function of non-reinforced stimulation, or whether the reticular formation is, in turn, controlled by cortical mechanisms (Grossman, 1967). In line with the former view Hernandez-Peon (1961) postulated a peripheral gating

mechanism to account for magnitude changes in the EP. Using decorticated cats, he demonstrated that the attentional phenomenon could be processed at the sub-cortical level, primarily at the caudle portion of the brainstem reticular formation. However, with higher-order functioning, such as concept learning, there may be an interaction of both cortical and sub-cortical mechanisms. In a study which indicates "generalization of habituation along a continuum of meaning in man," Rusinov and Smirnov reported that human Ss showed complete habituation to words with similar meanings (but different sounds). As soon as a word with a different meaning (but similar sound) was presented, Ss exhibited immediate and complete disinhibition of the auditory EP (cf. Grossman, 1967).

If Ss can selectively attend to certain stimuli which are relevant and ignore those that are not, then a cognitive interpretation would be favored. Recently, several studies have indicated that there are systematic changes in the magnitude of the late components of the VER correlated with selective attention and arousal. Attending to a particular stimulus resulted in an enhancement of EP patterns, and shifts in attention away from the stimulus resulted in a diminution of such activity (Donchin & Cohen, 1967; Eason, Harter, & White, 1969; Nätäänen, 1967; Spong, Haider, & Lindsley, 1965).

Ritter, Vaughan, and Costa (1968) found an increase in amplitude of the late positive component (LPC) and related the enhancement to stimulus novelty and the orienting response. They presented irrelevant tone stimuli at fixed intervals to Ss who were reading a book. Presumably, the subjects were ignoring the tones. However, when the tones were shifted to a different frequency, the first of the shifted tones produced a large LPC. In a later study, Ritter and Vaughan (1969) required Ss to respond to infrequent and unpredictably lower intensity signal stimuli and not to respond to the more frequent nonsignal stimuli. They, again, found an increase in the LPC for detected signal stimuli. Ritter and coworkers interpreted their findings in terms of central processes involved in a "cognitive evaluation" of the signal and nonsignal stimuli.

Several studies have also indicated that there is an enhancement in the LPC during information processing. Sutton, Braken, and Zubin (1965) found that when the identity of the second of two stimuli was uncertain, the vertex evoked response was much larger than when the second stimulus was known. In a follow-up study, Tueting (1968) found that the same component was also greater for low probability stimuli and for stimuli about which S had guessed incorrectly. In another study by Sutton and his coworkers, the LPC was absent when the subject knew what would occur. However, when the occurrence of the stimulus delivered

information regarding the occurrence of other stimuli, there was a large late positive component. Further, the absence of an expected stimulus also elicited the positive deflection (Sutton, Tueting, & Zubin, 1967).

Chapman and Bragdon (1964) demonstrated that differences in the physical energy of the stimulus do not always account for changes in VERs. Rather, these changes were related to stimulus meaningfulness in the sense of relevance to the task. Subjects were presented alternating intense flashes of light with less intense illuminated numbers. In one task, S was to select the lower of two numbers. His attention was, therefore, directed to the numbers, rather than the more intense blank flashes. Evoked responses to the numbers were found to be much larger than those to the flashes. Several criticisms have been raised against the study, which may hinder a cognitive explanation. One suggested that the heightened VERs may actually be OFF responses to the preceding blank flashes, since the dark period between stimuli lasted for only 40 msec. Another has been that since the interstimulus interval (ISI) was held constant at 750 msec., there was a possibility that Ss could alternate attending relevant and ignoring irrelevant stimuli.

Nätäänen (1967) prefers a noncognitive explanation of the enhancement of EPs. Nätäänen suggests that the increase in amplitude is due to differential anticipation and preparation for the regularly-spaced relevant and irrelevant

stimuli. However, in several studies where differential preparation was impossible due to randomly presented stimuli, the enhanced effect was still obtained (Spong et al., 1965; Ritter & Vaughan, 1969). Salmon (1971) has found that, with totally random presentation of signal and nonsignal stimuli, Ss will give larger responses to attended stimuli and decreased responses to unattended or irrelevant stimuli. These findings argue convincingly against the differential arousal suggested by Nätäänen.

Karlin (1970) also takes a noncognitive approach in explaining VER enhancement. He maintains that the differential response occurs for either one or both of two reasons. The first is that the probability of occurrence of the relevant stimulus is reduced when a relevant stimulus just precedes it. Therefore, the S can momentarily relax when a signal stimulus occurs because he feels that the next stimulus will be a nonsignal one. Secondly, upon presentation of the relevant stimulus and S's subsequent response, he can also relax as a result of task completion. Karlin suggests that the reactive potential (RP) resulting from these changes in state is independent of the sensory EP and has its own latency and amplitude. The RP interacts with the EP, resulting in a change of the late components of the EP or in a new deflection. This change is usually in terms of an enhancement in the LPC, which may partially account for the findings of the studies mentioned earlier.

Spong and Lindsley have integrated the effects of attention and arousal. They found that where differential levels of alertness or task difficulty were involved, both selective attention and arousal were operating. Selective attention emerged when the difficulty of the task was reduced and when the underlying arousal level was not sufficient to mask it. They suggested that, unless arousal level is extremely high, the enhancement in the VER may be due to both factors operating together (Lindsley, 1969).

The studies of Sutton and his coworkers, of Ritter, and of Chapman and Bragdon suggest that the peripheral gating mechanism postulated by Hernandez-Peon is not sufficient to account for magnitude differences in the evoked potential. Their findings indicate that the cortex must influence the functioning of the reticular formation, at least when there is stimulus uncertainty, information delivery, stimulus novelty, or the processing of task relevant information. These results are of particular significance to a concept learning task, which presupposes cognitive functioning.

Expectancy, Attention, and CNV

Another aspect of the human evoked potential is the slow direct current potential associated with anticipation, expectancy, and arousal, which Walter and his associates called "Contingent Negative Variation" (CNV) (Walter, 1964; Walter, Cooper, Aldridge, McCallum, & Winter, 1964).

These potential shifts are superimposed on the tonic component of the EP and are usually elicited only when the stimulus carries significant information to the organism. The region of maximum amplitude (usually 10 to 20 u v) for CNV is the vertex with latencies of 200 to 300 msec. and a duration of 500 msec. or more. Although these steady potential shifts are considered reliable cortical phenomena, their recordings are frequently contaminated with eye movements and are, therefore, difficult to fully interpret (Cohen, 1969).

The experimental paradigm most frequently adopted to elicit CNV involves a first, or conditioning, signal (S_1), a constant delay of one second or more, and then a second or response signal (S_2) which indicates the response is to be made. Following the evoked response to S_1, there is a slow negative shift from baseline which terminates with an abrupt positive deflection when S_2 is presented and the response is made (Cohen, 1969). This positive deflection either returns the potential to zero (i.e. baseline) or can overshoot baseline and become positive in polarity (positive-after-effect). The positive-after-effect is seen most often in complex situations where S_2 is essentially semantic and takes the form of a problem pattern or a provocative illustration (i.e. seminude females), which subjects tend to inspect in detail (Walter, 1964, 1965a).

Walter (1964) has suggested that CNV originates in the superficial plexiform layers of the cortex and represents a cortical "priming" which accelerates and synchronizes responses to associated stimuli. Further, the contingency wave is "the effect of increasing probability of association, that is the accretion of meaning, when the occurrence of the first stimulus always implies the arrival of the second [21]." CNV reflects the subjective rather than the objective association of stimuli.

Low, Borda, Frost, and Kellaway (1966) have confirmed that CNV is of cortical origin. They controlled for such peripheral effects as eye movements, Galvanic Skin Response (GSR), respiration, and heart rate. Although they found that downward eye movements were consistent with the CNV pattern, they also found CNV in subjects without eyes.

CNV can develop in a variety of situations. It will occur when a physical or mental response is made to S_2 (Walter, 1964; Walter et al., 1964; Low et al., 1966). It will also occur if verbal signals are used as S_1 ("ready") and S_2 ("now") (Walter, 1965b). It can be elicited by a cessation or change in the stimulus, or by external social influences which are related to the testing situation (Walter, 1964). CNV will also occur during a purely mental task, such as deciding when a certain time interval has elapsed (Walter et al., 1964). Several studies have reported that CNV is larger when a motor response to S_2 is

required, than when no response is required (Hillyard & Galambos, 1966; Irwin, Knott, McAdam, & Rebert, 1966; Low et al., 1966; Walter et al., 1964). Further, the contingency wave will gradually extinguish over trials if S_2 is withheld or if a response is no longer required (Hillyard et al., 1966; Low et al., 1966; Walter et al., 1964).

Many behavioral and physiological correlates have been postulated to account for CNV. Initially, Walter related the Expectancy Wave or CNV to the subjective significance of association of two stimuli. He also maintained that the E-wave reflected expectancy of S_2 (Walter, 1964; Walter et al., 1964). Motivational determinants have been suggested by Irwin and his associates (Irwin et al., 1966). They reported that when associational variables were held constant (e.g. constant ISI, constant stimulus duration, and no required operant response), CNV varied as a function of levels of finger shock. Under certain conditions, an inverse relationship between CNV magnitude and reaction time has been noted by Irwin and his coworkers (Irwin et al., 1966) and by Hillyard and Galambos (1966).

Conation or a specific mental state which denotes "a conscious drive to perform apparently volitional acts [781]" has been used to explain CNV (Low et al., 1966). Low suggested that CNV resulted primarily from the S's intention to respond and was therefore associated with conation. Systematic increases in the magnitude of CNV

with increases in the amount of force required to make the response have been reported by Low and McSherry (1967). Conative control was also demonstrated by McAdam, Irwin, Rebert, and Knott (1966). Using themselves as subjects, they found that they could consistently think "high" or "low" CNV.

Karlin (1970) has related arousal to these slow potential shifts. He suggests that CNV is an index of preparatory activity preceding the anticipated event. In studies of attention and arousal involving VERs, the positive-after-effect may introduce a positive deflection into the EP of relevant stimuli. The positive-after-effect could, therefore, account for an enhancement of the LPC of the evoked response. Karlin also suggests that the positive-after-effect is synonymous with the reactive potential (RP) mentioned earlier.

In a study with normal and neurotic subjects, McCallum and Walter (1968) investigated the effects of attention and distraction on CNV. They found that the high anxiety Ss showed a significantly smaller basic CNV than the normal group. When distracting stimuli (irregular tones) were presented, both groups showed a significant reduction in CNV. However, amplitude reduction was much smaller for the non-patient group. This finding is in line with the fact that many anxiety neurotic patients are easily distracted by

relatively minor events and, therefore, find it difficult to maintain selective attention.

In a second experiment in the same study, McCallum and Walter used various forms of distraction (E talking, music, simple to complex pictures) and found a reduction in amplitude of CNV. The extent of the reduction was a function of the degree of attention focussed on the distracting stimuli, and was not related to the stimuli directly relevant to the task.

Tecce (1971) has interpreted these findings in terms of a two-process model. He suggests that since CNV reduction is a function of distraction, then attention is positively and monotonically related to the magnitude of the slow potential. Attention is viewed as a selection or steering process that facilitates response to relevant stimuli, while excluding irrelevant stimuli. Distracting stimuli interfere with this process and therefore reduce CNV amplitude.

The second process relates the development of these slow potentials to general arousal. Under conditions of extremely low or high arousal, CNV is diminished. Within a normal range, however, CNV systematically increases in magnitude with increases in general activation. The function used to describe this relationship is, therefore, non-monotonic (inverted-U). Tecce views arousal as a

non-directional energizing phenomenon, which affects only the intensity of the response. He further maintains that arousal can interact with attentional functions in forming the response. Up to some optimum level, attention is facilitated by the general alerting process. Further increases in activation may result in attention impairment due to distracting internal stimulation.

Tecce's explanation of systematic changes in CNV amplitude due to the effects of attention and arousal is very similar to Spong and Lindsley's explanation of VER changes (Lindsley, 1969). The writer takes a similar view. In a concept learning task, it is highly probable that both factors are operating and interacting. The implication is that both peripheral and cortical mechanisms will influence the nature of the VERs to learning stimuli.

By withholding information about relevant and irrelevant stimuli, it is possible to examine evoked response changes in a situation where Ss must learn a discrimination (e.g. concept formation). If, in a learning situation, Ss selectively attend to some aspects of the stimulus which give them information regarding solution and do not attend to stimuli which they have learned are irrelevant, this discriminative process should be reflected in the VER, specifically the LPC.

Selective Attention and Concept Formation

Behavioral evidence has suggested that both human and infrahuman Ss selectively attend to certain aspects of the stimulus array in a learning situation. In studies where several stimuli are relevant and redundant (i.e. occurred together) throughout a problem, it has been determined that Ss often selectively respond to and learn only one of the relevant cues. Acquisition of the unpreferred cue as a relevant stimulus is essentially at chance level. Subjects apparently ignore the unpreferred relevant stimulus, even though it always appears with the preferred cue (cf. Trabasso and Bower, 1968).

Trabasso and Bower (1968) have suggested a three-step process of stimulus selection to account for this preferential attending. In their model, Ss initially search the stimulus array in order to select attributes or dimensions to which they will respond. Responses are then classified and connected with the levels of the selected dimensions (e.g. circle--yes, square--no; red--yes, green--no). The levels of the dimensions and their respective responses are referred to as hypotheses and S is considered to sample these hypotheses as a result of his search operation. Following selection of the hypothesis or focus sample, S then tests this sample against E's feedback information. If S is told he is correct, the sample is retained; if he is told he is in error, a

new focus sample is selected. This search-sample-test procedure continues until solution is reached.

Levine (1969) has postulated a similar theory to account for hypothesis testing behavior in human Ss. He suggests that there is a subset sample of hypotheses (Hs) from which S draws one as a tentative working hypothesis. The working hypothesis dictates S's response until it is disconfirmed. However, S is simultaneously monitoring the other Hs within the subset to determine whether they are also disconfirmed. If the working hypothesis is rejected, S draws another from the same subset. If all Hs within the subset are rejected, he establishes a new subset and selects another working hypothesis. This process continues until the correct H is selected.

Levine (1969) has also devised a blank-trials procedure which permits evaluation of hypothesis-testing behavior. The primary assumptions of the probe procedure are (a) S samples from a universe of hypotheses and responds according to the H selected, (b) S responds according to a single H during a series of blank trials, and (c) the universe of possible Hs is finite and known to E.

Under this method, two types of trials are given the subject. An outcome (feedback) trial is one in which Ss are given information about the correctness or incorrectness of their responses. On a blank trial, no information about their responses is given to the subjects. The first trial

of a problem is usually an outcome trial. Following the first feedback trial, sets of blank trials (usually a minimum of four) alternate with an outcome trial. Within a blank-trials set, the stimuli are arranged so that only one level of a stimulus pattern will correspond to a single response pattern. In this manner E can assess to which dimension S is responding (and presumably attending), simply by looking at the response pattern for a particular set. If S is not responding to a single dimension, he will give an uninterpretable response pattern. Levine (1969) and Eimas (1969) found that college students exhibit hypothesis-testing behavior (i.e. they gave interpretable response patterns) 92.4% and 88% of the time respectively.

Additionally, outcome trials are arranged in a manner that reduces the number of logical response alternatives by one-half following each feedback trial until only the correct response remains. This arrangement permits the assessment of S's ability to process information since their response patterns indicate whether their hypotheses are consistent with preceding outcome trials. The occurrence of consistent processing of information, or focusing, would lend support to the subset sampling theory. Levine found that in an eight-dimension problem, where solution could be logically focused upon the fourth outcome trial, Ss consistently reduced the number of outcomes to between 5 and 6 hypotheses out of a possible 16 Hs. Although Ss did not perfectly

process information, they did apparently attend to only certain aspects of the stimulus array when solving the problem.

These findings and the results of the relevant, redundant cue studies suggest that hypothesis-testing behavior is correlated with selective attention and will be reflected by VER enhancement and by the slow surface-positive D. C. potential shift. The present study attempts to investigate the positive deflections in the D. C. shift in a concept learning situation and to relate these deflections to hypothesis-testing behavior.

Method

Subjects

Four graduate students and two experimental psychologists served as subjects. Five of the six Ss had previously participated in evoked potential studies. The records of the remaining S were found to be consistently free of noise.

Concept Identification Task

Experimental problems. Each S had six one-hour experimental sessions, given on different days. In each session, S had to solve a simple concept identification problem. Each problem consisted of four dimensions with two levels in each one: shape of figure (circle or square), orientation of crossed bars (x or +), color of flash (red or green), and orientation of single bar (vertical or horizontal). The correct solution to each of the six problems was fixed by E and was one level of the relevant dimension. For instance, in Problem I, the relevant dimension was "shape" and the correct answer was "circle." Solutions to the five remaining problems were, in order, "horizontal," "x," "green," "vertical," and "square."

Within a problem, one trial consisted of the successive presentation of one shape, one of the crossed bar patterns, one color, and, finally, a single bar. Order of dimensions remained constant both within and across problems.

The fixed order permitted averaging of evoked potentials for each stimulus dimension and comparisons of these averages both across blocks of trials and across problems. Stimulus duration was 40 msec. and interstimulus interval (ISI) was 500 msec. Pilot data collected when S was told to selectively attend and not attend to stimuli indicated that systematic changes in VERs do occur with this interval.

Each trial was repeated four times with an intertrial interval (ITI) of 5 sec. One second following the fourth replication, an orange signal flash, which served as a cue for S's verbal response, was given. Following the orange flash, a new stimulus sequence, composed of two stimuli from the preceding trial and of two different stimuli, was presented and repeated for four trials. To illustrate, on the first trial of Problem I, S saw a square, a plus, a red flash, and then a vertical bar. During the next three trials, the stimuli remained unchanged. One second following the fourth trial, there was an orange flash. On the fifth trial S saw a circle, a plus, a red flash, and then a horizontal bar. This configuration was then repeated for three more trials. This procedure was followed since preliminary work indicated the necessity for replications in sets of trials, as opposed to a new sequence on each trial; it was found that, with the ISI and ITI used, Ss had difficulty in coding the stimuli and E could not efficiently make the appropriate sequence changes.

Blocks of 32 trials, and, therefore, eight different stimulus configurations, were summed to get an average VER. The two levels of each dimension were changed four times for the eight sequences. The evoked responses to each stimulus dimension, therefore, represented each level equally.

For the six problems, each S was instructed to give a verbal response when he saw the orange flash (see Appendix A for full instructions). He was to respond with "yes" if he felt the correct answer was in the preceding stimulus sequence, or "no," if he thought that it was not. Following the last trial in a 32-trial block and S's subsequent verbal response, E gave the subject feedback regarding the correctness of his last response. E told S "the correct response was yes" if the solution stimulus was one of the four in the preceding configuration or "the correct response was no," if it was not. Therefore, S was given outcome information only on the last of the eight different sequences.

In addition to the verbal response, on three of the six problems S had to make a Reaction Time (RT) response on each trial to the dimension he felt was relevant (i.e. one of the two levels was the solution stimulus). The subject was to release a key mounted on a response panel in front of his preferred (right) hand when the dimension he felt was relevant appeared. Since, on each trial, there was a sequence of four stimuli separated by an ISI of 500 msec., it was necessary to eliminate the possibility of S delaying his

intended response until the next stimulus occurred. Therefore, an auditory click was presented if S failed to respond within 350 msec. following a stimulus. For stimuli to which S did not respond, no click was presented. Pilot work indicated that the motor response and auditory click did not cause a noticeable change in the VER record.

As a result of the RT condition, on three problems S had to perform two response operations. His verbal response indicated the level of the stimulus S was testing and his RT indicated the dimension that contained that level. On the three no reaction time (NRT) problems, only the level of the tested dimension was indicated by S's verbal response. The verbal response was used to differentiate response patterns to the different levels of dimensions. A more detailed explanation of this procedure will be given later. VER enhancement to the tested dimension was anticipated for both the RT and NRT conditions; however, the effects were expected to be somewhat greater for the RT problems.

Blank-trials procedure. In order to establish hypotheses-testing behavior, a modification of Levine's blank-trials procedure (Levine, 1969) was used. As was mentioned earlier, outcome information was given following the last trial of every 32-trial block. The preceding 31 trials were blank (no-feedback) trials. Within a trial-block, the eight different stimulus sequences were

composed of two complementary sets of internally orthogonal stimuli (see Appendix B). This arrangement of stimulus sequences provided a unique response pattern for each level of each dimension within a trials-block. In this way E could assess to which stimulus S was attending for a series of trials. Across trials-blocks and problems, sequences were arranged so that no particular response pattern was overly associated with a particular sequence. S, therefore, could not easily anticipate the stimuli on a sequence change. A data sheet from Problem IV, which includes stimulus presentations and a S's responses is given in Appendix C.

Since the Ss in this study were already familiar with the hypothesis-testing procedure, they were instructed to maintain responding to one stimulus throughout a block of trials. This resulted in a uniform response pattern for each blank-trials set, and consistent responding for each problem.

Feedback trials were also internally orthogonal. This arrangement results in the reduction of logical outcomes by one-half after each outcome trial. With the four-dimension problem, if S remembers all the information from previous feedback trials and perfectly processes this information, he could know the correct answer after the third outcome trial.

Each problem was started with 31 blank-trials and an outcome trial. The number of following trial-blocks and, therefore, the length of each problem was determined by S's performance. Since Ss were familiar with the hypothesis-testing paradigm, they always solved the problems by the end of the third series of trials. They were, therefore, always testing the correct hypothesis on the fourth series, although, frequently, solution was reached before the fourth series.

Solutions to the six problems were selected on the basis of evoked potential sensitivity to attention as determined by pilot work; location within a sequence; representation of each dimension; and diversity of behavioral response patterns on outcome trials. Six was chosen as the optimum number of problems for several reasons. Initially, an equal number of problems was necessary for the RT-NRT conditions. With four problems, S could easily eliminate possible solutions after three problems and know which dimension had not been tested. Further, it was felt that with eight or more problems, Ss would become less motivated and, therefore, less attentive.

Experimental Design

In a preliminary session, S was read the instructions, which explained the possible solutions (i.e. the dimensions and their levels) and the response alternatives. He was given two practice problems (one under RT and one under

NRT) in order to familiarize him with the problem procedure and with making the responses.

Each experimental session was initiated with a brief reminder of the instructions and with several practice trials. The latter served to stabilize S's EEG record and allowed him to practice his RT response when it was necessary. A session ended when S reached criterion. Criterion was established as three consecutive correct responses on outcome trials following the second feedback trial. This criterion insured at least five blocks of trials for each problem and at least three blocks with S responding to the solution stimulus. Since Ss always perfectly processed outcome information they reached criterion on either the fifth or sixth block of trials.

As mentioned earlier, each S participated in six experimental sessions. In each session he was given a different problem. During three of the sessions he had to make both a verbal response and a reaction time response, while in the other three sessions he was required to make only the verbal response. In addition, each S was assigned a different problem order and a different RT-NRT order. Problem assignment for the six subjects was determined by a 6 x 6 Latin Square. The RT-NRT conditions were superimposed upon the Latin Square so that each subject had three RT and three NRT problems. Additionally, each of the six problems was given three times under RT and three times under NRT.

Finally, each of the six sessions was represented equally by the two conditions. An illustration of the Latin Square used is given in Appendix D.

Since changes in VERs as a function of selective attention during learning were of major concern, evoked response changes to relevant (i.e. solution) and irrelevant (i.e. nonsolution) stimuli were investigated. For statistical analysis, responses to these two conditions were averaged separately. The resulting averages were composed of a greater number of responses for nonsolution than solution stimuli. This was due to the fact that there were three nonsolution stimuli and only one solution stimulus within a problem.

In order to ascertain differences in VERs as a function of time within a problem, trial-blocks (one through five) were treated as another variable. Although Ss frequently needed six trial-blocks to reach criterion, the sixth block was eliminated to simplify statistical analysis. Additionally, since all Ss were on solution during the fourth block, five blocks of trials gave an adequate measure of post-solution performance.

Reference has been made frequently in this section to "changes in VERs as a function of selective attention." Changes in the slow positive potential shifts were implicit in this reference. In order to obtain a D. C. shift measure, shifts from baseline for each stimulus on a trial were measured, These measures were summed and an average was

obtained. This average was then subtracted from each stimulus shift on that trial, resulting in a transformed score for each stimulus. These transformed scores served as a dependent measure for the D. C. shift data. Transformations were necessary, due to fluctuating baseline and movement artifacts in the data.

The design for the D. C. shift data, then, consisted of three variables: solution and nonsolution responses; reaction time and no reaction time conditions; and the five blocks of trials for a problem.

Apparatus and EEG Recording

Stimulation. Since the evoked responses to both levels of a stimulus dimension were averaged together in a block of trials, it was necessary to minimize the possibility of different waveforms canceling each other out. A previous study in the same laboratory (Salmon, 1971) and pilot studies indicated that the stimuli chosen had sufficiently similar waveforms to minimize these effects.

The eight stimuli were presented at two hertz on the high contrast screen (approximately 28 mm. in diameter) of a LVE Model 1346 Multiple Stimulus Projector. The apparent intensities of the patterns, in log units above threshold were as follows: circle and square, 3.00; x and +, 2.90; red, 2.70; green, 2.80; and vertical and horizontal bars, 2.90. The amplitude of the shapes and bars was approximately 20 mm. Since the flashes of color filled the screen of the

stimulus panel, they were approximately 28 mm. in diameter. The screen of the Multiple Stimulus Projector was surrounded by a 55 x 70 cm. piece of white cardboard positioned approximately 66 cm. from where the S was seated. The S was told to avoid movements and to fixate the center of the display at all times during a run, resulting in a visual angle of 2.4 degrees.

The experiment was conducted in a partially sound-proof, electrically shielded room, with background illumination (.656 ml) provided by an overhead projector. Although dark adaptation had shown no noticeable effects in pilot studies, S adapted for approximately five minutes at the beginning of a session to provide added control.

The Multiple Stimulus Projector was programmed to present the stimuli in trains of four with an ISI of 500 msec. and an ITI of 5 sec. After every fourth trial, E changed two of four toggle switches (one for each dimension) which determined the stimuli presented. Also, during the fourth ITI, an orange flash was presented on the screen one sec. following the last stimulus. This signalled S to give a verbal response, which was recorded by E.

For problems on which S was to make a reaction time response, a Grass and Stadler Model 1B noise generator was programmed to give an auditory click if he failed to respond within 350 msec. (i.e. a miss) following a stimulus. The click did not occur if S did not respond to a stimulus. In

order to mask extraneous noise, the noise generator also provided background (white) noise for all problems.

A digital counter recorded the number of elapsed trials during a problem. By monitoring the counter, E knew when to change the toggle switches for a new sequence. Counters also recorded the total number of responses and the number of misses on RT problems. Since the RT was an easy one, E could determine the alertness of S by the number of misses and could caution him about his responses.

Trials were presented in blocks of 32 with a between-blocks interval of approximately 2 to 3 minutes. One blank-trials block therefore lasted 224 seconds. The between-blocks interval provided a rest period for S and permitted E to print out the VER records.

VER recording. Evoked responses were measured by silver disc electrodes placed at the vertex (Cz) and one inch above the inion (Oz), with a reference electrode attached to the right ear lobe. Upon placement, skin resistance was less than 10,000 ohms. Electrodes were held firmly in place by a rubber electrode band and by electrician's tape.

Electroencephalograms were fed into a Grass Model 7-WC Polygraph. Frequency filters were set at .3 hertz for the 1/2 amplitude high frequency filter. Systematic changes in the DC shifts had not been anticipated but these cut-offs were sufficient, though not optimal, for differentiating them.

EEG records were monitored for muscle tension, movement, and other potential artifacts on both the polygraph and a Hewlett Packard 141A Oscilloscope. Similarly, the actual presentation of the physical stimuli was monitored on the screen of a Multiple Stimulus Projector mounted outside the experimental room.

Evoked responses were averaged by a Fabri-Tek Model 1062 Instrument Computer, which was triggered by the first stimulus of each trial. VERs for a set of blank-trials and the following feedback trial were summed and averaged for a total of 32 trials. Sensitivity was set at 2048, with a dwell-time of 2 msec., and a sweep-time of 2560 msec. Since order of presentation of each stimulus dimension was constant, each sweep contained four evoked potentials (one corresponding to each stimulus dimension). An example of subject R. H.'s raw data from three problems is given in Figure 1. Four channels of the computer were used to record, simultaneously, the evoked responses from the occipital and vertex electrodes, the reaction time distribution, and the four stimulus markers. The signals were printed out on graph paper by a Hewlett Packard 7035B Recorder.

Baselines for the D. C. shift data were obtained by the averaging technique explained earlier. Deviations of the sequence shifts from baseline were used to determine the effects of the learning task under both the RT and NRT conditions.

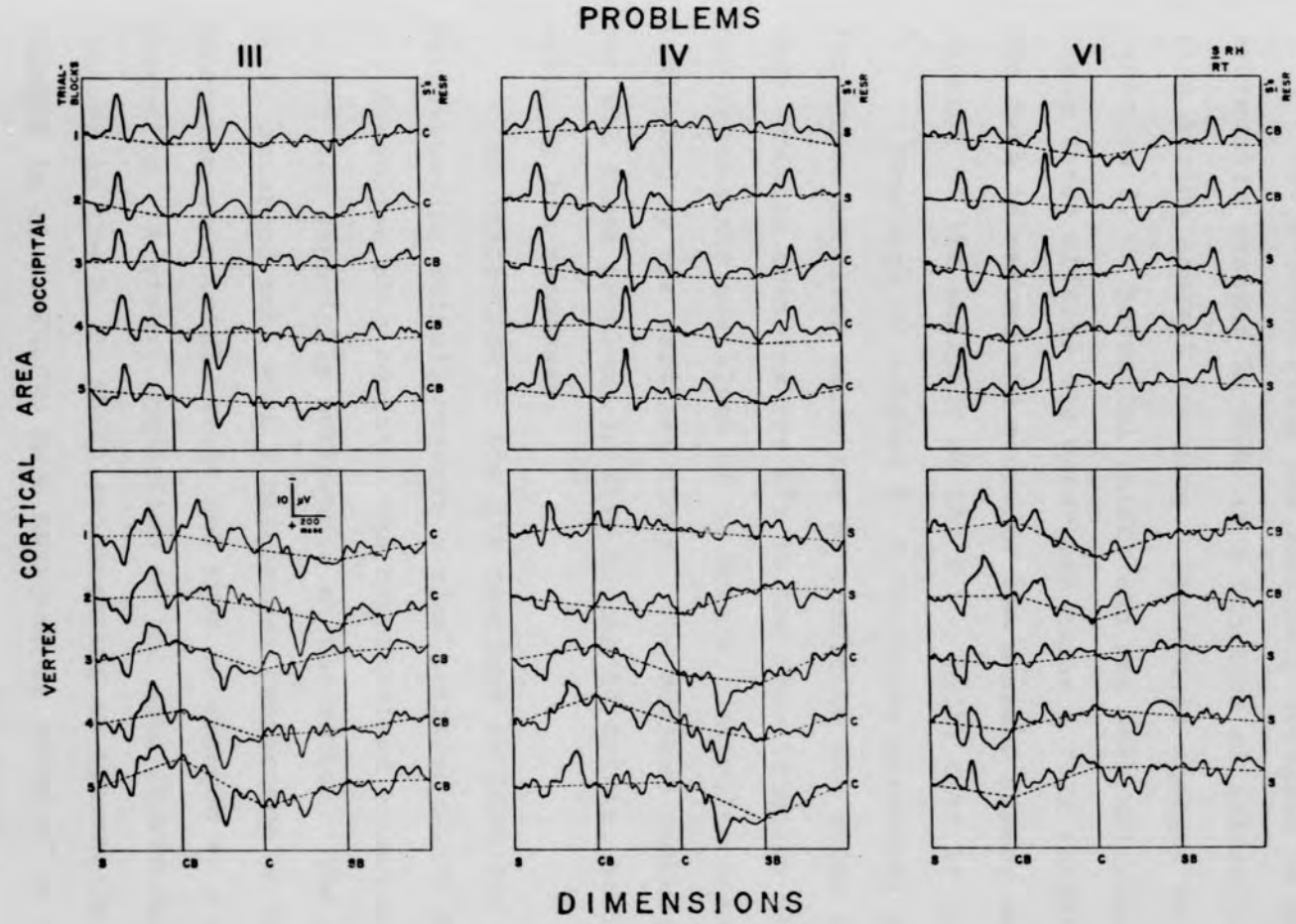

Fig. 1. Subject R. H.'s evoked responses and DC shifts recorded at the Occiput (O_z) and the vertex (C_z) for reaction time problems.

Results

The present study was initially designed to measure systematic changes in VERs as a function of selective attention during concept learning. Systematic changes in the slow positive D. C. potential shifts had not been anticipated. Since these effects did occur and since a full analysis of the data is beyond the scope of the present paper, only a portion of the analysis of the D. C. shift data is discussed.

Tracings of subject R. H.'s evoked potential patterns for three problems under the RT condition are given in Fig. 1. Each tracing contains the EPs to the four stimulus dimensions and represents one block of 32 trials. Stimulus onset is indicated by the vertical lines. The subject reached criterion for all three problems in five blocks of trials, as is indicated by his responses.

An inspection of the S's response pattern and of the corresponding stimuli reveals a slow positive shift following the dimension that contains the hypothesized stimulus. This effect was especially noticeable at the vertex. The positive shift occurred both when S maintained responding to one dimension over trial blocks and when he changed to a new dimension. A visual inspection of the data showed reliable changes in the D. C. shift accompanying an hypothesis change. Changes in D. C. shifts were measured in terms of an increase or decrease in polarity from the potential shifts of corresponding stimuli on the preceding trial-block. An

hypothesis-shift (H-shift) away from a stimulus appeared to result in an increasingly negative D. C. shift, with the reverse being true when the H-shift was toward a stimulus. A Sign Test was performed on the difference scores occurring when S shifted responding from one hypothesis to another over trial blocks. Results of the Sign Test were significant for both total negative D. C. shifts away (29 reversals out of 92 comparisons, $p < .01$) and for total positive D. C. shifts 34 reversals out of 92 comparisons, $p < .05$) stimuli. Summing over the RT-NRT conditions and the directions of the shifts, significant results were also obtained for both the vertex (28 reversals out of 92, $p < .01$) and the occiput (35 reversals out of 92, $p < .05$). In order to determine under what conditions and at which location the effects were most noticeable, additional Sign Tests were performed differentiating the RT-NRT conditions and the location of the recordings. Results were significant ($p < .01$) for both occipital (13 reversals out of 50) and the vertex (9 reversals out of 50) recordings under the RT condition. No significant results were obtained for the NRT condition.

In order to establish any differences in the slow positive D. C. shifts due to attending to solution and nonsolution stimuli, an analysis of variance was performed on the transformed scores. As mentioned earlier, scores were averaged differentially for solution (only one per problem) and nonsolution stimuli (three per problem) across problems.

Since a visual evaluation of the data and the Sign Test both indicated somewhat lesser effects for the occipital recordings, an analysis was performed separately on the occipital and the vertex data. Since the transformed data were deviations from an average for each trial-block, significant results were anticipated for only the Solution-Nonsolution variable. However, the possible occurrence of any interactions was also of interest. As expected, positive D. C. shifts were significant for the Solution-Nonsolution conditions at both the occipital lobe ($F = 10.19$ with 1,5 df; $p < .05$) and the vertex ($F = 13.10$ with 1,5 df; $p < .05$). None of the remaining conditions and interactions was significant. Summary tables for both analyses are given in Appendix E.

The upper row of Fig. 2 gives the D. C. shift trends for solution and nonsolution stimuli averaged across problems for each S. Since the trends were most apparent at the vertex under the RT condition, only those graphs are given. The sixth trial-block is included in the figure for Ss who occasionally needed six blocks to reach criterion. Although trend continuation is apparent for those Ss with six trial-blocks, it was necessary to eliminate these points in the analysis of variance due to the unequal number of levels for the trial-block variable. The trials graphs reflect a variation in responding for the first three trial-blocks for all Ss. This was expected, since there was considerable variability in behavioral responses to relevant and irrelevant

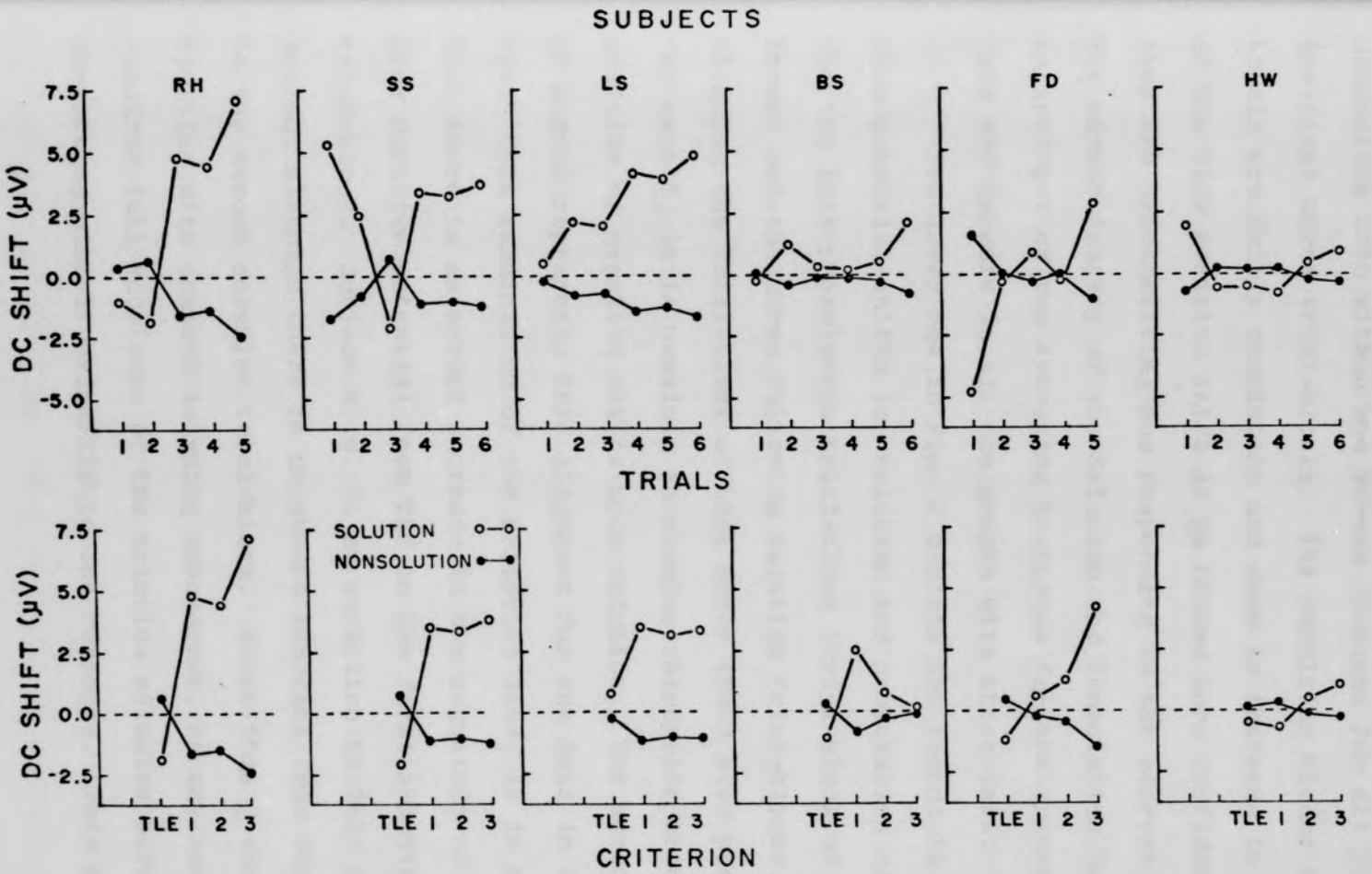

Fig. 2. DC shifts after solution and non-solution stimulus for each subject recorded at the vertex (means of 3 RT problems aligned at Trial 1 and at TLE).

dimensions both within and across problems for all Ss during the first three trial-blocks. The remaining blocks of trials are fairly consistent and show an increase in magnitude of the slow positive shift as Ss become more confident that they are hypothesizing and responding to the correct stimulus. The mirror imagery of the Solution and Nonsolution trends is an artifact of the averaging technique for the transformed data and appears in all the graphs with these data.

The lower row in Fig. 2 depicts the trends in the slow potential shifts for solution and nonsolution stimuli for the last presolution trial-block (Trial-block of Last Error) and the three following solution trial-blocks. By aligning the Trial-block of Last Error (TLE) over problems for each S, it is possible to examine increasing trends in positive or negative shifts upon solution. The second row of graphs represents this alignment for the data in the first row. Upon examination of the criterion data, it is evident that there is an abrupt increase in the magnitude of the slow positive potential from TLE to the first solution trial-block. Subject H. W. is an exception to this generalization, although there is an abrupt increase from the first to the second solution trial-block. Since this S was very familiar with concept learning procedures, he may have required full knowledge of the solution stimulus before committing himself primarily to one response. This knowledge

would have always been available by the second solution series.

Comparison across the two portions of the figure reveals a consistency between the Trials and Criterion data, although the abrupt increase in the positive DC shift is more apparent in the latter. The absence of the step-function in the Trials data for some Ss is due to the fact that, over problems, they began hypothesizing the solution stimulus on different trial-blocks and the resulting trials averages attenuated the effect.

In order to determine if the same trends occurred under all conditions, group averages were obtained for the Trials and Criterion data. Fig. 3 shows the response conditions (RT and NRT) at both recording sites for the two types of data. As reflected by the individual Ss data in Fig. 2, the increment in the positive DC shift over trials occurs consistently at the vertex under RT. The effect is true for both the Trials and the Criterion measures. Although the remainder of the grouped trials data do not reflect any strong systematic changes, an increase in amplitude of the positive shift for the Solution stimulus occurs over trials under the NRT condition for the Criterion measure. The step-function from TLE to the first solution trial which is so prominent under RT at the vertex, is missing under NRT. However, in both cases the direction of the shift for solution stimuli is positive, while nonsolution stimulus shifts

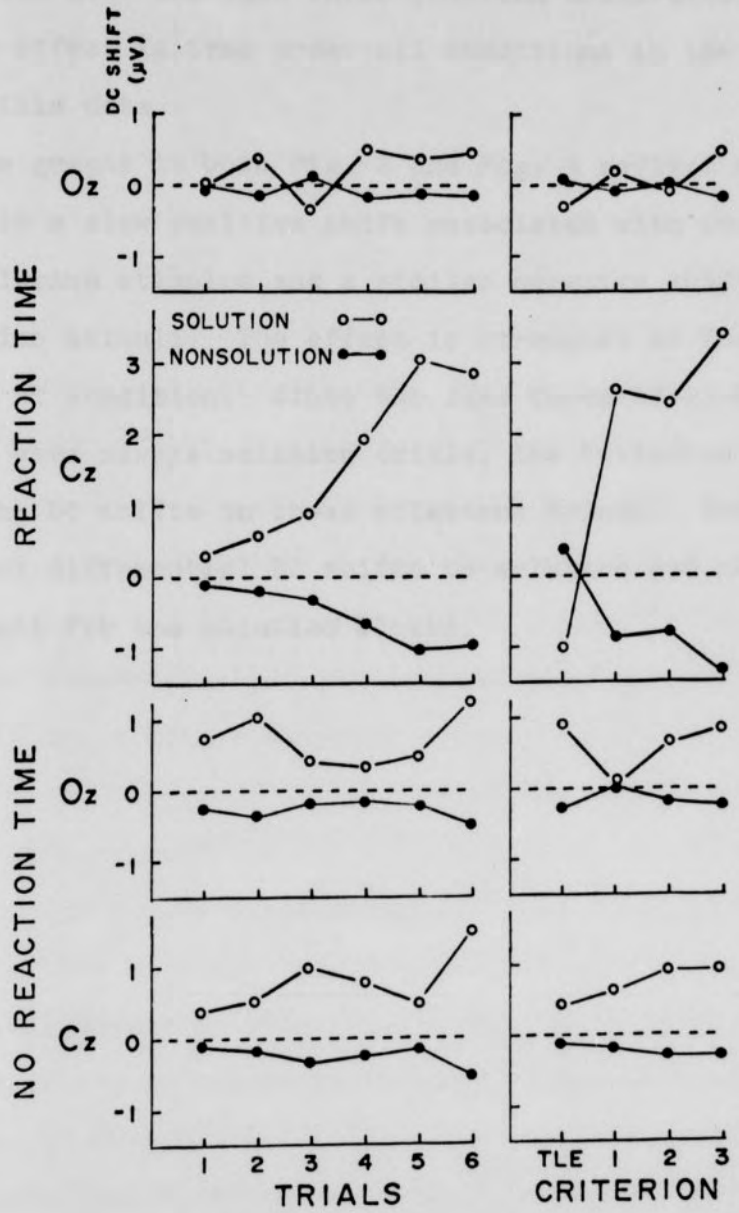

Fig. 3. Means for solution and nonsolution DC shifts (averaged across Ss and problems) under reaction time and no reaction time conditions.

are negative over the last three solution trial-blocks. This same effect is true under all conditions in the graph of the Trials data.

The graphs in both Fig. 2 and Fig. 3 reflect a general increase in a slow positive shift associated with responding to the solution stimulus and a similar negative shift to non-solution stimuli. The effect is strongest at the vertex under the RT condition. Since the last three trial-blocks in a problem were always solution trials, the Criterion data reflect the DC shifts on those solutions trials. These data reveal differential DC shifts to solution and nonsolution stimuli for the solution blocks.

Discussion

It has been shown that when Ss shift hypotheses in a concept learning situation, there is a comparable shift in the slow DC potential. A positive shift occurs to the hypothesized or attended stimulus, but is no longer evident when the stimulus is not attended. A visual examination of R. H.'s data in Fig. 1 suggests that it would be possible for a naive observer to select the dimension to which S was attending simply by looking at the slow shifts from baseline. Since these records reflect potential averages to both the correct and incorrect stimulus level of the relevant dimension, the effects are probably somewhat attenuated and would have been greater if the potentials to only the correct stimulus level had been averaged.

Although a more thorough analysis of the correspondence has yet to be completed, the results of the Sign Tests suggest a systematic relationship between S's hypothesis-testing behavior, as reflected by his behavioral response, and changes in DC potential shifts. As mentioned earlier, hypothesis-testing is viewed as a process whereby Ss selectively attend to or focus on some subset or sample of the stimulus array. They then test this sample during feedback and retain or reject once outcome information is given (Levine, 1969). It is suggested that the DC shifts reflect

the initial and, perhaps, the second portion of this process. This suggestion follows from the findings of McCallum and Walter (1968) and Tecce (1970) which suggest that CNV may be an index of selective attention.

Since significant results were not obtained in the Sign Test for the NRT conditions, it could be argued that the DC shifts reflect only anticipatory and termination responses to the RT stimulus. However, the same trends, though not significant, occurred in the NRT data (see Figs. 2 and 3). Due to the four replications of each sequence, S had an easy task in processing information about the stimuli contained within a sequence. Further, under RT, he needed only attend to every fourth trial in order to give his verbal response. The attentional effects, therefore, were greatly reduced by the fact that, for NRT, S found it necessary to selectively attend to only eight of the 32 trials. Under RT, the same effects were much greater, since S had to not only give a verbal response, but also, attend to all 32 trials in order to give an RT response. The number of required attention trials was, therefore, much less for the NRT condition and is probably reflected in the non-significant CNV record.

Although results were significant for both the slow positive and negative shifts, it was felt that an analysis of the slow positive potential was more appropriate since the ISI (500 msec.) was relatively short for full negative

slow potential development. Further, it was often impossible to determine whether a negative shift was a response to a stimulus or an anticipation of the following stimulus. Since the positive potential always terminated during the ISI following an hypothesized stimulus, it was a consistent index of the response to a particular stimulus. Additionally, Walter's findings (1964, 1965a) indicated that the positive potential was greatly enhanced for complex problems in which meaningful stimuli were used. For these reasons, the slow positive potential was chosen for further analysis.

The analysis and graphs indicate a significant relationship between positive DC shifts and attending to solution stimuli. Although the nature of the transformed scores do not permit quantitative statements regarding DC shift enhancement, statements regarding the direction and slope of the shifts can be made. An inspection of the graphs for the Trials grouped data (Fig. 3) indicates that the effect is optimal at the vertex for the RT condition. This finding is in accord with those of Walter et al. (1964), Irwin et al. (1966) and Hillyard and Galambos (1967) who found greatest CNV at the vertex during reaction time problems. Under all conditions, however, the Ss are always giving positive DC shifts by the fourth trial-block. The fourth trial-block was also the one on which Ss had eliminated all but the solution stimulus, since they always perfectly processed

previous outcome information. They were, therefore, always responding to solution stimuli by the fourth series.

The variability in presolution responding, reflected in the Trials data for Figs. 2 and 3, is accounted for by the fact that Ss were either responding to irrelevant dimensions or were responding to either the correct or incorrect level of the relevant dimension. Occasionally Ss would test the correct answer and then return the hypothesis to the pool of possible solutions before receiving full confirmation. Additionally, some Ss solved the problems before the fourth series.

In order to establish the effects of solution responding upon DC shifts, the criterion measure was used. The close correspondence between solution responding and the positive DC shift is better illustrated by these data, since the TLE and solution trial-blocks are aligned and are, therefore, somewhat equivalent across problems. In the Criterion data for individual Ss (Fig. 2) and group averages (Fig. 3) there is an obvious abrupt positive deflection, once S begins post-solution responding. For the group data, the exception was at the occipital lobe, under RT. This exception does not hinder an attentional interpretation, since the occipital lobe has been shown to only poorly reflect DC shift changes (Cohen, 1969).

The abrupt positive deflection from TLE to the first solution trial for the individual Ss corresponds nicely with

an all-or-none interpretation of learning. All-or-none theorists maintain that upon solution, responding goes from chance level to a probability of one. Although data points preceding the TLE are needed to fully evaluate the graphs, the abrupt positive shift from TLE to the first solution trial indicates a comparably abrupt change in the positive potential upon solution. Apparently, upon solution, Ss are fairly certain they have mastered the problem and, therefore, focus in on the solution stimulus. Any increase after solution may reflect S's gaining confidence in his responses, as he eliminates all stimuli of which he was still unsure. This finding is consistent with behavioral evidence which indicates that when solution is reached S may still be testing several hypotheses. In succeeding solution trials S may further eliminate all of the incorrect hypotheses remaining in his subset and reduce the size of the hypothesis sample to the correct one (Levine, 1969). If further analysis done separately for each of the irrelevant stimuli should reveal similar and stable positive DC shift trends over presolution trials for these stimuli accompanied by the corresponding abrupt shift at TLE to the solution stimulus, then a possible neurophysiological measure in support of the all-or-none model could be forthcoming.

Another plausible interpretation of the abrupt shift which would appeal to incremental learning theorists and

to peripheralists is in terms of arousal and the anticipation of a motor response. It could be argued that when S begins responding to the solution stimulus, he is highly aroused. In most cases this arousal is due to the fact that S is either almost certain of a correct response or he knows that if the responded-to stimulus is incorrect, his response set will then be reduced to one and he will know the answer by the end of the series. In either case, S is highly expectant with regard to making his response to the stimulus and this expectancy and arousal are reflected by his CNV.

The writer takes the view that the positive-after-effects of CNV are actually reflecting attentional processes in concept learning. Further analyses designed to measure magnitude changes in DC shifts should reveal a correlation between the S's behavioral response and the positive DC potential.

Summary

VERs to stimuli in a concept learning task were measured to determine if there were systematic changes in DC shifts associated with hypothesis-testing behavior. It was found that when Ss shifted from one hypothesis to another, there was a corresponding shift in the negative and positive components of slow potential. The effect was most noticeable at the vertex under a reaction time condition. Further analysis indicated that the positive potential shift reflected behavioral responding when it was measured in terms of solution and nonsolution stimuli.

These results were interpreted in terms of attentional processes to concept learning stimuli.

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Appendixes

Appendix A

Instructions to Ss

This is a concept identification study. In this study, you will be given several easy problems. Each problem consists of four dimensions with two levels in each dimension. The four dimensions are: shape (either a circle or a square), orientation of crossed bars (either a + or an X), color (either red or green), and orientation of single bars (either a vertical or horizontal bar).

For each problem, only one of the dimensions is relevant (i.e. one of the two levels of that dimension is the correct solution to the problem). For example, in a problem, the relevant dimension may be color and the correct solution is red. Your task is to learn the correct solution (i.e. level of the relevant dimension) to the problem.

Within a problem, one trial will consist of the sequential presentation of one level of each of the four dimensions. For example, on the first trial you might see in sequence a circle, a +, the color red, and a horizontal bar. One trial will be repeated four times before going on to a new sequence. Immediately following the fourth trial of a particular sequence an orange light flash will signal you to give a verbal response. You are to respond "yes" if you feel the correct stimulus is in the sequence, or "no," if you feel that it is not. Within a series of Blank trials, you will always make your verbal response to

the same stimulus. Blank trials are those on which you get no outcome or feedback information as to the correctness of your response. Once outcome information is given, you may change your responses to another stimulus. On some problems, you will also have to make a reaction time response following the dimension you feel is relevant. An auditory click will occur if you fail to respond within 350 msec. following that dimension. If you don't respond fast enough, your response will appear to be to the next dimension in the sequence. In making the reaction time, lift your finger as quickly as possible after the stimulus and return it to the key at the end of the sequence. This will help to eliminate motor artifacts in your data.

Occasionally, I will tell you whether or not your verbal response is correct. Following an outcome trial, there will be a short rest while I'm printing out the data. Try to remember all of the information you learned on the preceding series during the rest period.

The criterion for learning will be three correct responses in a row on outcome trials, following the second series.

At all times during a series, fixate the center of the display. Try not to blink during a sequence or during every fourth inter-trial-interval. If you blink during the fourth ITI you may fail to see the orange flash and, therefore, not give your verbal response.

Appendix B

Response Patterns for Orthogonal Stimuli
(Example)

Trials	Stimulus Patterns			
	Shape	Cr. Bars	Color	S. Bars
1-4	circle	x	red	v
5-8	circle	x	green	h
9-12	square	x	red	h
13-16	square	x	green	v
17-20	circle	+	red	v
21-24	circle	+	green	h
25-28	square	+	red	h
29-32	square	+	green	v

Trials	Response Patterns							
	Shape		Crossed Bars		Color		Single Bars	
	circle	square	x	+	red	green	v	h
1-4	yes	no	yes	no	yes	no	yes	no
5-8	yes	no	yes	no	no	yes	no	yes
9-12	no	yes	yes	no	yes	no	no	yes
13-16	no	yes	yes	no	no	yes	yes	no
17-20	yes	no	no	yes	yes	no	yes	no
21-24	yes	no	no	yes	no	yes	no	yes
25-28	no	yes	no	yes	yes	no	no	yes
29-32	no	yes	no	yes	no	yes	yes	no

Appendix C

Data Sheet

Trials	Series	Shape	Cr. Bars	Color	S. Bars	Correct Response	Subject's Response	Rt	Miss	Hypoth-esis
1-4	1st	circle	x	red	v		yes			
5-8		circle	x	green	h		yes			
9-12		square	x	red	h		no			
13-16		square	x	green	v		no			
17-20		circle	+	red	v		yes			
21-24		circle	+	green	h		yes			
25-28		square	+	red	h		no			
29-32		square	+	green	v	yes	no	30	4	circle
1-4	2nd	square	x	green	v		yes			
5-8		circle	+	green	v		no			
9-12		circle	x	red	v		no			
13-16		square	+	red	v		yes			
17-20		square	x	green	h		yes			
21-24		circle	+	green	h		no			
25-28		circle	x	red	h		no			
29-32		square	+	red	h	no	yes	32	0	square
1-4	3rd	circle	+	green	v		yes			
5-8		circle	+	red	h		no			
9-12		circle	x	red	v		no			
13-16		circle	x	green	h		yes			
17-20		square	+	green	v		yes			
21-24		square	+	red	h		no			
25-28		square	x	red	v		no			
29-32		square	x	green	h	yes	yes	31	0	green

Data Sheet (continued)

Trials	Series	Shape	Cr. Bars	Color	S. Bars	Correct Response	Subject's Response	Rt	Miss	Hypoth - esis
1-4	4th	circle	x	green	h		yes			
5-8		square	+	green			yes			
9-12		circle	+	green	v		yes			
13-16		square	x	green	v		yes			
17-20		circle	x	red	h		no			
21-24		square	+	red	h		no			
25-28		circle	+	red	v		no			
29-32		square	x	red	v	no	no	32	0	green
1-4	5th	circle	x	red	h		no			
5-8		square	x	green	h		yes			
9-12		square	+	red	h		no			
13-16		circle	+	green	h		yes			
17-20		circle	x	red	v		no			
21-24		square	x	green	v		yes			
25-28		square	+	red	v		no			
29-32		circle	+	green	v	yes	yes	32	1	green
				Criterion						
1-4	6th	square	x	green	h					
5-8		circle	x	green	v					
9-12		square	x	red	v					
13-16		circle	x	red	h					
17-20		square	+	green	h					
21-24		circle	+	green	v					
25-28		square	+	red	v					
29-32		circle	+	red	h	no				

Data Sheet (continued)

Trials	Series	Shape	Cr. Bars	Color	S. Bars	Correct Response	Subject's Response	Rt	Miss	Hypoth-esis
1-4	7th	square	+	green	v					
5-8		square	x	red	v					
9-12		square	+	red						
13-16		square	x	green	h					
17-20		circle	+	green	v					
21-24		circle	x	red	v					
25-28		circle	+	red	h					
29-32		circle	x	green	h	yes				
1-4	8th	square	x	green	h					
5-8		square	+	green	v					
9-12		circle	+	green	h					
13-16		circle	x	green	v					
17-20		square	x	red	h					
21-24		square	+	red	v					
25-28		circle	+	red	h					
29-32		circle	x	red	v	no				

Appendix D

Latin Square for Problem Assignment

Problems I-VI

Sessions 1-6

Ss 1-6

Reaction Time R

No Reaction Time N

	1	2	3	4	5	6
S_1	I N	II N	III R	IV R	V N	VI R
S_2	II R	V N	I R	III N	VI R	IV N
S_3	V R	I R	IV N	VI R	III N	II N
S_4	VI N	IV R	II R	V R	I N	III N
S_5	III R	VI N	V N	II N	IV R	I R
S_6	IV N	III R	VI N	I N	II R	V R

Appendix E

Table 1

Analysis of Variance: Occipital Recording

Source	df	Ms	F
Between Ss	5		
Within Ss	19		
Reaction Time (RT)	1	2.74	
Solution (Sol)	1	36.75	10.19*
Trial-Blocks (TB)	4	.65	
RT x Sol	1	10.95	
RT x TB	4	.48	
Sol x TB	4	2.60	
RT x Sol x TB	4	1.90	
Between x Within Ss	95		
S x RT	5	10.58	
S x Sol	5	3.61	
S x TB	20	1.01	
S x RT x Sol	5	42.23	
S x RT x TB	20	.67	
S x Sol x TB	20	4.03	
S x RT x Sol x TB	20	2.68	
Total	119		

*$p < .05$

Table 2

Analysis of Variance: Vertex Recording

Source	df	MS	F
Between Ss	5	3.99	
Within Ss	19		
Reaction Time (RT)	1	7.34	
Solution (Sol)	1	209.14	13.10*
Trial Block (TB)	4	3.76	
RT x Sol	1	29.54	
RT x TB	4	3.53	
Sol x TB	4	15.15	
RT x Sol x TB	4	14.01	
Between x Within Ss	95	8.52	
S x RT	5	7.16	
S x Sol	5	15.97	
S x TB	20	3.86	
S x RT x Sol	5	28.71	
S x RT x TB	20	2.45	
S x Sol x TB	20	15.48	
S x RT x Sol x TB	20	9.76	
Total	119		

* $p < .05$